Chamber Technology Roadmapping

Presented by

R.F. Mattas

Argonne National Laboratory

Presented at DOE-VLT Review, April 4, 2000

Members of Group

- Leslie Bromberg - MIT
- Mike Gouge - ORNL
- Rich Mattas - ANL
- Wayne Meier - LLNL
- Farrokh Najmabadi - UCSD
- Dave Petti - INEEL
- Mike Ulrickson - SNL
- Alice Ying - UCLA
- Steve Zinkle - ORNL

Outline

- General Considerations
- Background and Approach
- Summary of work to date
- Emerging Themes
- Future Effort

Areas Included

- Materials
- Safety
- PFC
- FW/Blanket
- Fueling/Pumping
- Advanced Design

Background

- At a VLT meeting last year following Snowmass, group members expressed a desire to improve interactions and the development process among areas.
- At the request of Charlie Baker, a small group was organized to specifically address Chamber Technology.
- It was decided that MFE Chamber Technology would be addressed first and then later integrated with IFE.

General Considerations

- Chamber Technology is a complex area with numerous goals, variables, and disciplines.
- Several steps are necessary before a Roadmap can be constructed.
- We have a good start on the activity, but planning is at a relatively early stage.
- All comments and suggestions are welcome.

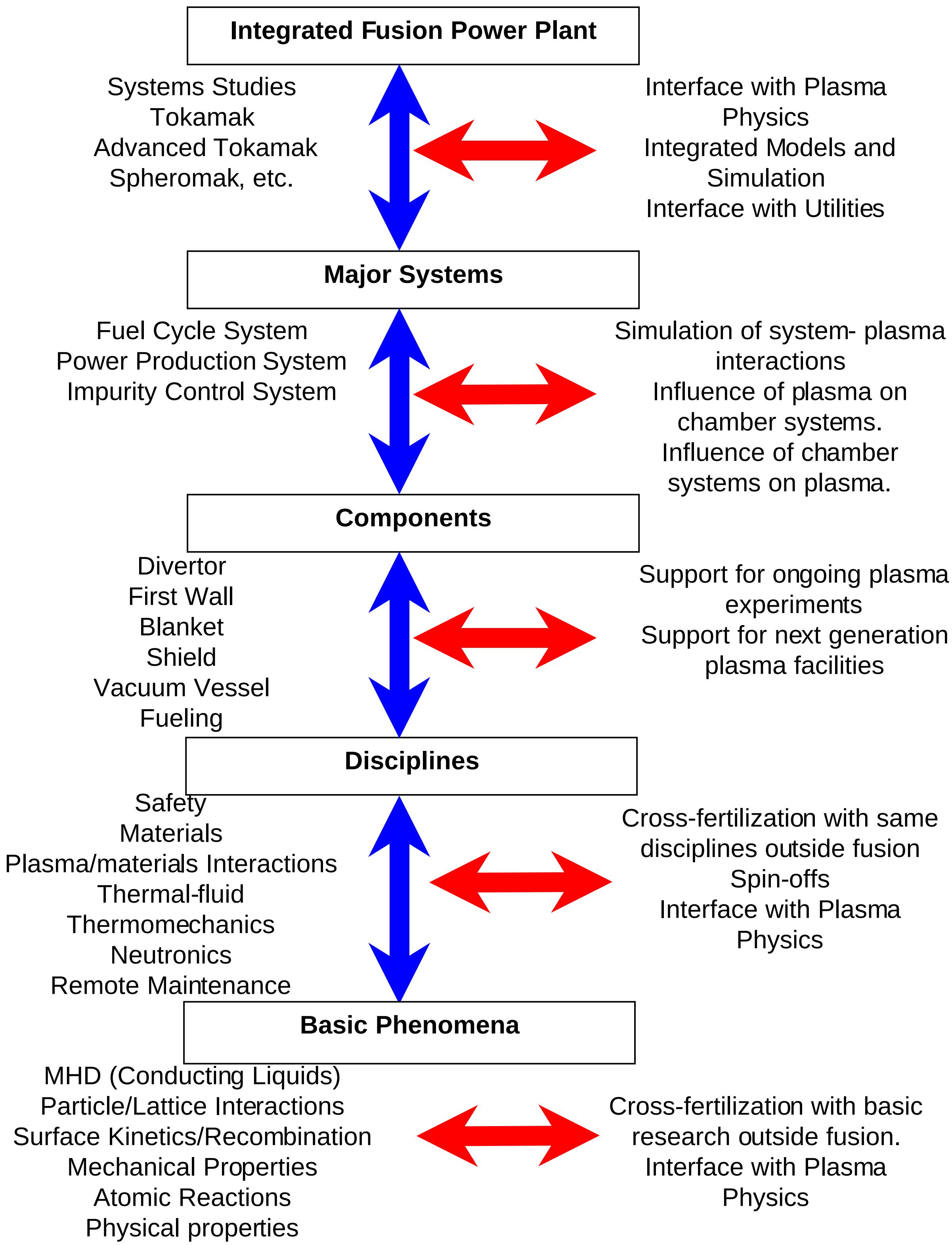
Approach

- The lead person for each area prepared a 2-3 page summary.
  - Goals
  - Issues
  - Ongoing work
  - Future effort
- The summaries provided a basis to begin identifying connections between areas and common themes.

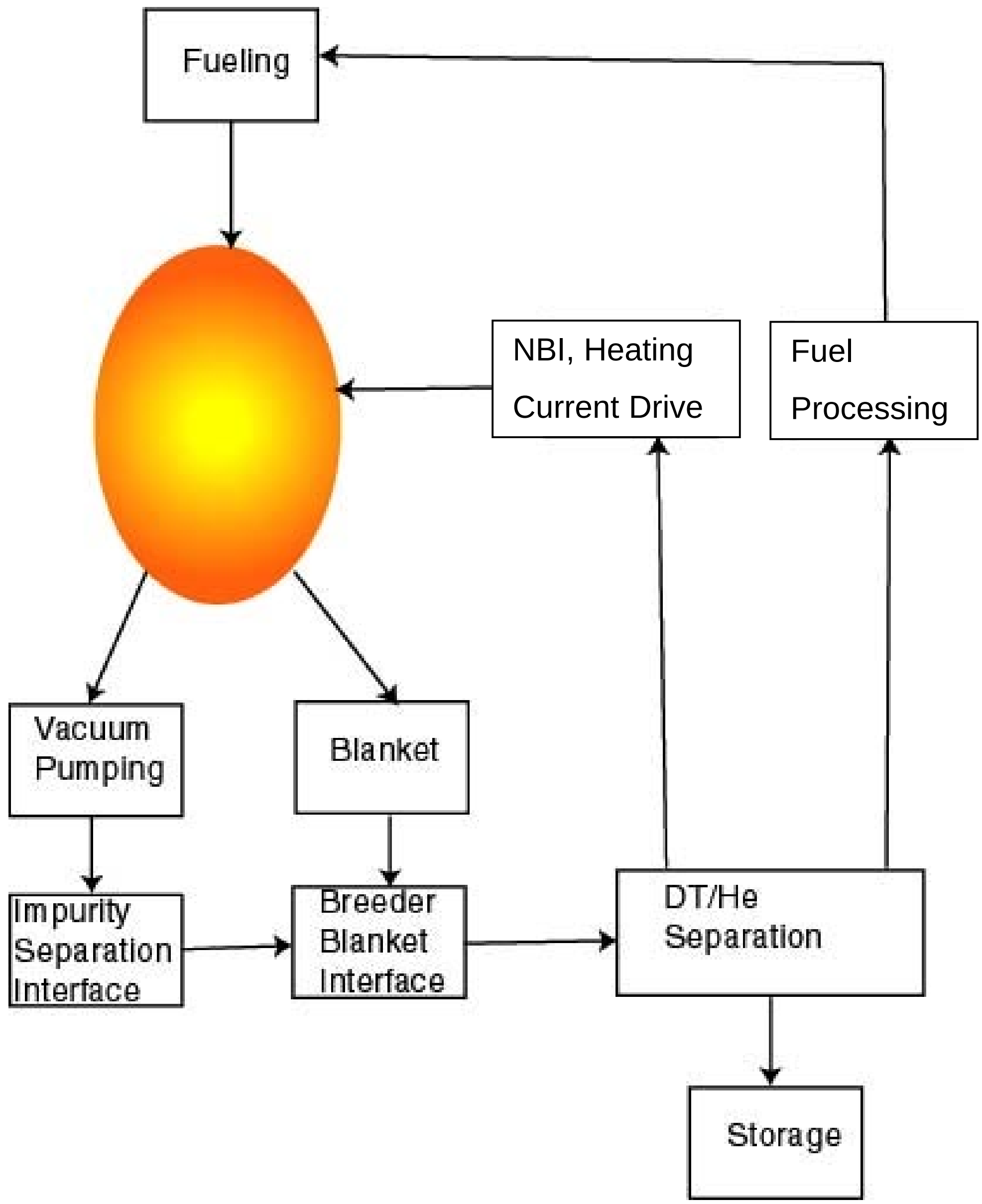
Approach (cont.)

- Information was identified and organized via e-mail and conference calls.
  - Key input from other areas and output to other areas to help understand important connections
  - Key issues and questions
  - The present status of ongoing development
- Tables and graphics were developed to illustrate connections.
- Guidelines established by FESAC were used as much as possible

Hierarchy for Chamber Technology



Fuel Cycle System



Summary of Chamber Technology Work

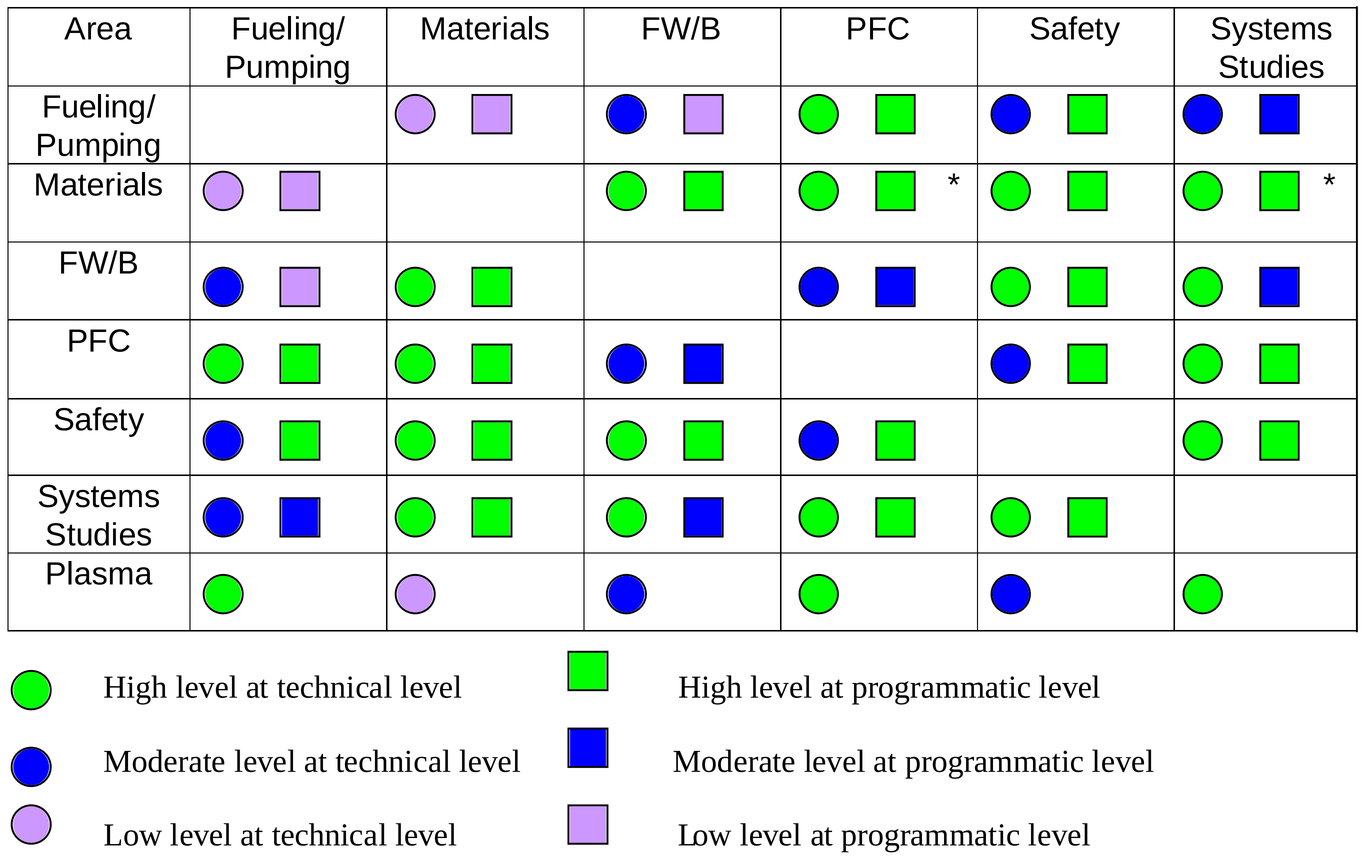
Area of Chamber Technology	Relevance to Engineering Research	Long-term Research Objectives
Materials	• Understand the effects of irradiation of on the properties of materials. • Understand the effects of environment on the properties of materials. • Develop models of materials behavior that are validated against experimental data.	• Develop structural materials that will permit fusion to be developed as a safe, environmentally acceptable and economically competitive energy source. • Provide information and expertise on advanced materials to other technology areas to improve system performance and attractiveness.
Fuelling/ Pumping	• Provide state-of-the-art systems to plasma physics community to enable advances in plasma physics • Understand the physical principles and scaling of high field pellet launch physics as well as understand the physical principles of fueling by dense plasmoids • Develop pellet diagnostic systems that can improve understanding of plasma physics.	• Develop fueling and pumping systems with sufficient performance to maintain the specified plasma density profiles and edge conditions at mass throughputs relevant to fusion energy systems. • Understand fueling and exhaust issues for liquid walls and divertors.
Plasma Facing Components	• Understand particle-surface interactions for both solids and liquids. • Develop models of plasma-materials interactions for both solids and liquids. • Develop and validate models for thermal hydraulics for channel and free surface liquid systems at very high power loads. • Provide plasma facing materials, technology and components necessary to enable advances in plasma physics. • Develop a unified plasma core, plasma edge and plasma materials model that is validated against experimental data.	• Develop plasma-facing components that are plasma compatible and can remove a steady-state surface heat flux of 50 MW/m^2 without the need of periodic maintenance to renew the plasma-facing material. This goal may be accomplished through the deployment of plasma facing components with free surface liquids; or with non-sputtering, helium-cooled refractory components protected from off normal heat loads by transpiration cooling.
First Wall and Blanket	• Understand (magnetic)hydrodynamics flow (channels and free-surface liquids) feasibility in the complex geometry including penetrations needed for plasma maintenance. • Understand heat transfer at free surface and temperature control including effects of radiation spectrum, surface deformation, velocity and turbulent characteristics.	• Explore, understand, and identify high pay-off chamber technology concepts that can enhance the potential of fusion as an attractive and competitive energy source. • Contribute to international development of conventional systems.

	• Develop models of hydrualics and heat transfer that are validated against experimental data. • Develop models of integrated behavior of first wall/blanket systems.	
Safety	• Understand the behavior of the largest sources of radioactive and hazardous materials in a D-T machine (e.g., activation products, dust, tritium, Be,) • Understand how energy sources in a fusion facility (e.g., magnets, plasma, decay heat and chemical reactions) could mobilize those materials • Develop integrated state of the art safety models validated against experimental data.	• Assess/evaluate safety and environmental issues associated with emerging fusion concepts to demonstrate the safety and environmental potential of fusion
Advanced Design	• Understand the engineering environment that plasma support technologies and fusion power technologies should operate at and the constraint imposed by operation of other systems. • Understand the contribution of each system towards the goal of an attractive fusion system. • Identify shortcomings of present data base and where further data is essential	• Assess the relative merit of potential advancement in each area of science and technology and its contribution towards the common goal of attractive fusion power plants.

Chamber Technology Disciplines and Components

Disciplines	Comments	Components	Comments
Materials	• Separate technology area for structural materials • Other materials work performed in PFC, blanket, and safety areas	**PFC**	• Strong interface to existing and next generation devices • Long term focus through ALPS • Design work in APEX and NSO
Safety	• Separate technology area • All safety work is performed within this area	**First Wall**	• Aspects of First Wall fall in both PFC and Blanket areas • Almost all solid first wall development is being done outside U.S.
PMI	• PMI work is performed within the PFC area • Strong interface with plasma edge physics	**Blanket**	• Long term focus through APEX and ARIES. • Only very limited experimentation now taking place in U.S.
Thermal--fluid (with magnetic field)	• T -F work is performed within the PFC and Blanket areas	**Shield**	• Tied closely to blanket • Limited systems design work through ARIES, NSO
Systems design	• Separate technology area with work within ARIES and NSO programs. • Other work is included in APEX, ALPS	**Vacuum Vessel**	• Design work in NSO
Thermomechanics	• Thermomechanics work is performed within the First Wall, Blanket, materials and PFC areas. • T-M is used in evaluating and specifying the processing conditions for materials, and are also applied for irradiation tests, and some types of mechanical testing.	**Fueling/Pumping**	• Not strictly a Chamber Technology component, but has strong interaction with PMI and PFC. • Strong interface to existing and next generation devices.

Level of Interaction



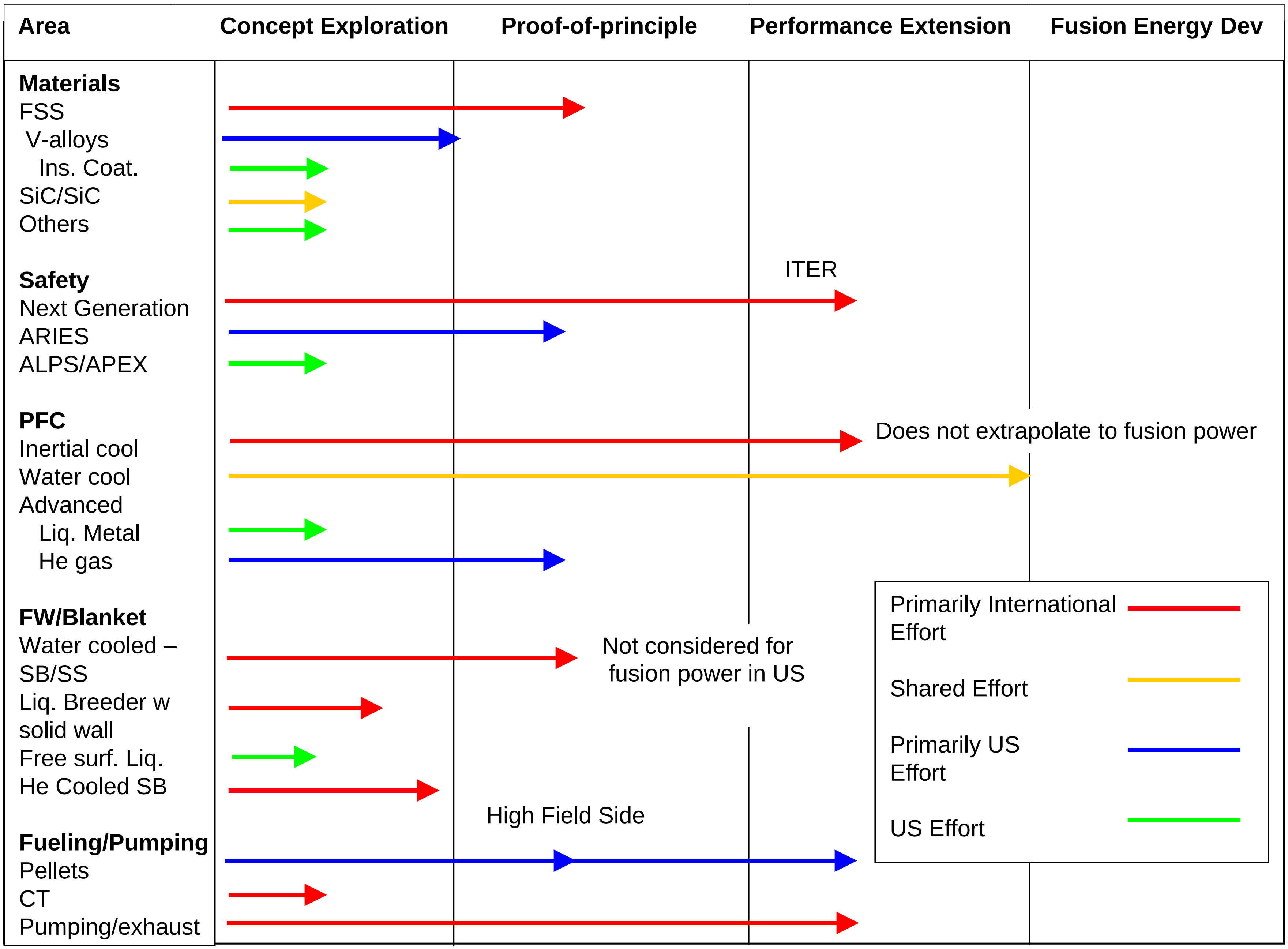
* Level of interaction is good but increased level is desirable

Important Connections between Chamber Technology Areas

Area	Input information needed from other areas (Specify Area)	Output information supplied to other areas (Specify Area)
Fueling/ Pumping	• *PFC/FW* materials will impact fueling and pumping due to recycling • Some liquid metals (Li) are not compatible with gas fueling and efficient He exhaust • Need allowable tritium inventory and confinement requirements for fueling and pumping systems from *Safety* • Plasma-fueling rates required & plasma conditions & Helium generation rates	• Closely coupled to *Plasma* via fueling/exhaust physics (efficiency, burn fraction, ELMs, L to H mode, PEP mode, He exhaust, etc.) • Coupled to *PFC/FW* due to recycling fuel source, compatibility of fueling and pumping with liquid metal walls, etc. • Coupled to *Safety* via burn fraction, T throughput and inventory, fast plasma shutdown, disruption mitigation • Fuel efficiency and burn fraction impact required tritium breeding ratios • Plasma-particle removal rates & fuel source rate
Materials	• PFC & FW/B – operating conditions & design of components • Structural materials selection criteria (Safety, Design and FW/B communities)	• PFC&FW/B – Materials properties before and after irradiation & new materials and forms • Operating temperature and dose limits for FW/B systems (Design and FW/B communities)
FW/B	• Plasma edge conditions (Plasma) • Operating temperature limits of structural materials (Materials) • Fueling and heating requirements including penetration size and shape (Fueling and heating) • Same as PFC • Plasma- neutron flux	• Impurity source term for plasma edge conditions (Plasma) • Characterizations of liquid-bulk plasma interaction and limitations on heat loads (FW/B and Plasma) • Definition of operating environment for materials and requirements on material properties (Materials) • Source terms for safety evaluation (Safety) • Information on thermomechanics and other interactions of breeder/structure/multiplier/coolant (Materials, Safety) • Same as PFC Plasma- wall stabilization Safety- tritium inventory
PFC	• Plasma-heat & particle loads, magnetic forces • Materials-properties & irradiation & allowables • Safety- operating temperature limits	• Materials- design & operating conditions • Plasma- impurity generation rates & tritium retention, heat flux limits • Safety- tritium inventory

Safety	• PFC&FW/B- operating conditions & failure modes Materials- Failure modes • Design input • Coolant material choice (Flibe, LiSn, LiPb, Li) • Structural material choice (conventional LAMs, W, Mo, Ta)	• PFC&FW/B-Operating temperature limits • Waste management criteria and what it means for materials choice • Safety aspects of fusion liquids (chemical reactivity, mobilization, waste) • Safety aspects of conventional LAMs and refractories (chemical reactivity, mobilization and waste) • Safety aspects of divertor materials (chemical reactivity, mobilization, tritium inventory and mobilization) • Safety and environmental assessments of ARIES, APEX, IFE and FIRE designs
Advanced Design	• Technical data base, what is possible	• What is important, R&D goals and priorities
Plasma	• PFC&FW/B- impurity sources and sinks, tritium sources • Fueling- particle losses	• All-plasma conditions, heat loads, particle loads

Status of Development for Chamber Technology



International Cooperation

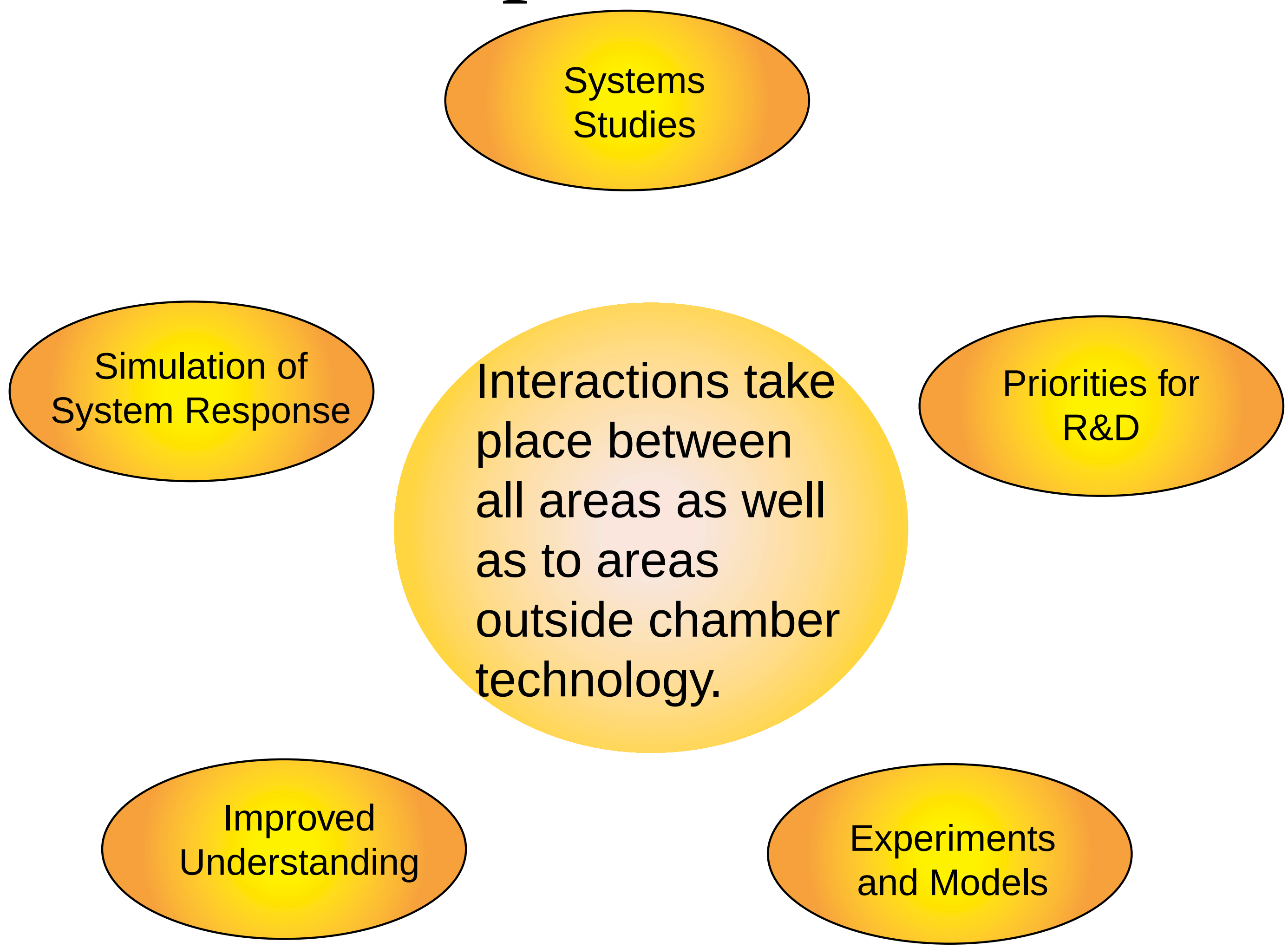
Area	Information supplied to the US from international partners	Information supplied to world program by the US.
Fueling/ Vacuum	• Plasma-pellet physics data from ASDEX, JET, Tore Supra; • Pellet ablation data from ASDEX, JET, Tore Supra, LHD, Textor	• Plasma fueling technology (techniques, designs, hardware) to LHD, JET, Tore Supra, Textor • Pellet ablation database to international community • Fueling methods and cryopump designs
Materials	• Ferritic/martensitic steel R&D (production of large heats, thermophysical properties, T_2 barriers, ferromagnetic effects, etc.) • Advanced SiC fibers (Japan) • Vanadium alloy (NIFS heat) • Irradiation data • Ferritic materials data • **both information and tangible products (e.g., ferritic/martensitic steel and V alloy reference heats and advanced SiC fibers)	• Vanadium alloy R&D (processing, rad. effects, creep, MHD insulators, US program reference heat) • SiC/SiC R&D (processing, rad. effects, creep) • Deformation and fracture methodology • Vanadium materials data • SiC materials data • **both information and tangible products are supplied (e.g., vanadium alloy reference heats and advanced SiC fibers)
FW/B	• R&D information on evolutionary concepts, including solid breeder blanket concepts and self-cooled liquid blankets. • Fabricated materials (e.g. ceramic breeders). • DNS modeling for free-surfaces • Solid breeder materials data	• Leadership of identifying and advancing innovative concepts. • Contributions to evolutionary concepts on insulator coating, ceramic breeders and beryllium thermomechanics. • Liquid breeder data
PFC	• Water cooled technology and manufacturing techniques • PMI/PFC data from LHD, JT-60U, JET, ASDEX, Tore Supra, TEXTOR, etc.	• Liquid surface PFC operating conditions and designs • Wall conditioning techniques for LHD • PFC design collaboration for KSTAR, LHD, Tore Supra • He cooled heat sink data • PMI modeling codes such as REDEP, A*THERMAL, UEDGE, etc.
Safety	• Data for validation of fusion safety codes MELCOR and ATHENA(IEA safety collaboration) • Access to international tokamaks for dust collection • Samples of Be, W and CfC for safety testing • Waste management hazard vs. volume and criteria (IEA safety collaboration) • Risk/Failure Rate Database (IEA safety collaboration)	• Use of US fusion safety codes MELCOR and ATHENA(IEA safety collaboration) • Data on chemical reactivity of materials in next step machines (e.g., irradiated Be, W brush) • Data on dust characterization in tokamaks and dust formation models • Failure rate data for database (IEA safety collaboration) • Activation product volatility testing of fusion materials (e.g., irradiated SiC) • Safety codes • Volitilization data • Tritium limits

Effort Distribution

Area	% Concept Exploration	% POP	% Performance Extension
Materials	70	30	0
FW/B	100	0	0
PFC	50	30	20
Safety	35	50	15
Fueling/Pumping	30	30	40

- CE and POP levels mainly support FESAC Goal 4
- Performance Extension level mainly supports FESAC Goals 1-3

Chamber Technology Development Process



Considerations for Development Process

- Design and systems studies necessarily go beyond existing technology knowledge base, and needed R&D is identified.
- Generally the time cycle for experiments and model validation is longer than the time cycle for design studies
- Systems studies and R&D go on in parallel.
- It is important to maintain close interactions between the design and R&D communities.

Emerging Themes

- A common thread connecting activities is modeling and simulation.
- A trend is integration of simulation codes into larger, more complex packages.
- Common access to database information and code modules will be important for integrating areas in Chamber Technology

Future Effort

- Use information to develop Roadmap as part of larger Fusion Roadmap activity.
- Combine MFE and IFE Chamber Technology planning
- Explore and implement ways to improve development process
  - Database accessibility
  - Simulation code development and integration
  - Interactions with plasma physics
  - Identification of metrics and process to make decisions